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Red List Indices to measure the sustainability of species use and impacts of invasive alien species

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Summary

After habitat loss and degradation, the leading threats to biodiversity are over-exploitation and invasive alien species. For birds, newly synthesised data using the standard classification schemes for utilisation and threat types for the IUCN Red List allow novel analyses on the importance of these threats and permit the calculation of Red List Indices (RLIs) to show trends in the status of birds driven by these factors. At least 45.7% of extant bird species (4,561 species) are used by humans, principally for pets (37.0%) and for hunting for food (14.2%), but other uses include sport hunting, ornamentation and traditional medicine. Much of this use drives trade at an international scale, involving at least 3,337 species (33.9%, substantially higher than previous estimates), mostly for the pet trade. RLIs show that although successful control and management of use and trade have led to some species improving in status, this has been outweighed by the number of species deteriorating in status owing to unsustainable exploitation. Overall, the RLI showing trends in extinction risk driven by issues related to use shows a negative slope: human use of birds is currently unsustainable. Similarly, and of relevance to the Convention on the International Trade in Endangered Species (CITES), the RLI for internationally traded bird species showing trends in extinction risk driven by issues related to international trade is also declining: international trade remains a threat to the world's birds. Invasive species impact at least one third of the world's threatened bird species (398 species, 32.6%), with mammals being the most important (impacting 81.1%), particularly through predation by carnivores and rodents. The RLI illustrating impacts of invasive species shows that they are driving a deterioration in the status of the world's birds. RLIs for the impacts of use and invasive species will be important indicators to help track progress towards the target of significantly reducing biodiversity loss by 2010.

Introduction

The human population has now passed six billion people and continues to grow (United Nations Secretariat 1999). Concomitantly, the planet's biodiversity is being diminished at an ever-accelerating pace, with genetic diversity being lost, populations shrinking, species being driven to extinction and ecosystems becoming disrupted and fragmented (Millennium Ecosystem Assessment 2006). These impacts on biodiversity have direct consequences for the ecosystem services upon which human societies depend, and ultimately therefore for human health and well-being (Vitousek *et al.* 1997). After habitat loss and degradation (with its multiple drivers), unsustainable exploitation and invasive alien species (IAS, hereafter 'invasive species') spread by human activities are the two largest drivers of biodiversity loss (Baillie *et al.* 2004).

Indicators for the 2010 target

Recognising the far-reaching impacts of the accelerating rate of loss of biodiversity, the intergovernmental Convention on Biological Diversity (CBD) committed in 2002 'to achieve, by

2010, a significant reduction of the current rate of biodiversity loss at the global, regional and national levels as a contribution to poverty alleviation and to the benefit of all life on earth' (decision VI/26). Later in 2002, this commitment was endorsed by 189 governments at the World Summit on Sustainable Development (WSSD) in Johannesburg.

The '2010 target' has stimulated the search for, and development of, suites of indicators to track trends in the rate of biodiversity loss (Mace 2005, Pereira and Cooper 2006). The most influential and widely accepted set of indicators was that adopted by the CBD at its seventh Conference of the Parties in 2004 (Decision VII/30). This framework recommended the development of indicators in seven focal areas: status and trends of the components of biological diversity, sustainable use, threats to biodiversity, ecosystem goods and services, traditional knowledge, access and benefits sharing, and resource transfers.

Under the theme of sustainable use, two indicators were proposed: (a) area of forest, agricultural and aquaculture ecosystems under sustainable management; and (b) proportion of products derived from sustainable resources. Neither of these addresses the impact of use on natural systems. Similarly, under the theme of threats to biodiversity, two indicators were proposed: (a) nitrogen deposition; and (b) numbers and costs of invasive species. Again, neither of these indicators tracks the impacts of specific threats on the status of biodiversity.

In recognition of the limitations of the two proposed indicators of sustainable use, an Ad Hoc Working Group on Sustainable Use Indicators convened by the IUCN SSC Sustainable Use Specialist Group and UNEP-World Conservation Monitoring Centre recommended a number of additional indicators, including a version of the IUCN Red List Index to measure impacts of use on the extinction risk of sets of species (Ad Hoc Working Group on Sustainable Use Indicators 2006). Similarly, in a report to the CBD, Kümpel and Baillie (2007) reviewed available data and potential indicators for tracking trends in invasive species. They recommended a number of possible indicators which were then reviewed by an *ad hoc* working group for their policy relevance, scientific rigour and geographic representativeness (Mace and Taylor 2007). Among the ten indicators that were prioritised was one measuring 'Trends in impact of invasive species on the conservation status of species' based on the IUCN Red List Index (Mace and Taylor 2007). This indicator also appeared in the final shortlist of four measures that were selected for further development by the Global Invasive Species Programme under the 2010-Biodiversity Indicators Partnership.

The Red List Index

The IUCN Red List Index (RLI) measures trends in the overall extinction risk of sets of species (Butchart *et al.* 2004, 2005, 2006a, 2007). It is based on data from the IUCN Red List (www.iucnredlist.org). This is generally recognised to be the most credible and authoritative system available for classifying species in terms of their risk of global extinction (de Grammont and Cuarón 2006, Rodrigues *et al.* 2006). The IUCN Red List uses criteria with quantitative thresholds based on population size, rate of decline, and area of distribution to assign species to categories of relative extinction risk, ranging from Least Concern, through Near Threatened, Vulnerable, Endangered and Critically Endangered to Extinct in the Wild and Extinct (IUCN 2001, 2005). The criteria are clear and comprehensive, and incorporate uncertainty (Akçakaya *et al.* 2000). For each species classified on the IUCN Red List, assessments are supported by detailed documentation, including information on range, occurrence, population, trends, habitat preferences, threats, utilisation, and conservation actions in place and needed (Rodrigues *et al.* 2006).

The IUCN Red List is becoming increasingly comprehensive in terms of taxonomic breadth, with all species now assessed in several major classes, including birds (1988–2008), mammals (1996–2008), amphibians (2004), conifers (1996) and cycads (2000–2008). Furthermore, global assessments are underway to assess all reptiles, marine species in several groups (including sharks and coral-reef fish), several freshwater groups, and selected plant groups (initially legumes and trees).

The RLI uses information from the IUCN Red List to track trends in the projected overall extinction risk of sets of species. It is based on the number of species in each category on the IUCN Red List, and changes in this number over time resulting from genuine improvement or deterioration in the status of individual species (i.e. category changes resulting from improved knowledge or revised taxonomy are excluded).

The RLI was initially designed and tested to show trends for all bird species (Butchart *et al.* 2004), and has since been applied to amphibians (Butchart *et al.* 2005). By 2010, RLIs will also be available to show trends for all mammals, conifers and cycads, and for a much more representative set of taxa based on a random sample of all vertebrates and selected plant groups (Baillie *et al.* submitted). Baseline estimates will also be available for all reptiles, selected freshwater, plant and marine groups, and (based on a random sample) selected invertebrate groups. As well as tracking global trends, the RLI can be disaggregated to show trends for species in different biogeographic realms, ecosystems, habitats, and taxonomic groups (Butchart *et al.* 2004, 2005, 2007). The RLI can also be applied at the regional (I. J. Burfield and S. H. M. Butchart unpublished data), national (Randrianasolo *et al.* submitted) and subnational scales (Quayle *et al.* 2007).

The RLI has been widely recognised and recommended as one of the suite of indicators needed to track progress towards the 2010 target (Brooks and Kennedy 2004, Millennium Ecosystem Assessment 2005, Pereira and Cooper 2006, Rodrigues *et al.* 2006, Secretariat of the Convention on Biological Diversity 2006, UNEP 2006). An indicator on 'Trends in the status of threatened species' has been moved into the top group of indicators for 'immediate testing' by the CBD Subsidiary Body on Scientific, Technical and Technological Advice (Secretariat of the CBD 2005). In addition, RLIs based on the relevant sets of species have been adopted or are currently being considered for adoption by the Ramsar Convention on Wetlands, the Convention on Migratory Species (CMS), the Agreement on the Conservation of Albatrosses and Petrels under the CMS, the African-Eurasian Waterbird Agreement under the CMS, and the Streamlining European Biodiversity Indicators-2010 initiative (coordinated by the European Environment Agency, the European Centre for Nature Conservation and UNEP-World Conservation Monitoring Centre). Finally, the RLI will be used to report against the newly adopted indicator 'proportion of species threatened with extinction' for the United Nations Millennium Development Goal 7: 'ensure environmental sustainability'.

This paper responds to the call to develop RLIs showing trends in the impacts of use (and its sustainability) on the status of species, and trends in the impacts of invasive species; it presents two new sets of RLIs using data on the world's birds from 1988 to 2004.

Methods

Calculating RLIs

The methods for calculating the RLI have been described in detail in Butchart *et al.* (2004, 2005, 2007). Here I use the improved formula and presentation recommended by Butchart *et al.* (2007). This is:

$$RLI_t = 1 - \frac{\sum_s W_{c(t,s)}}{W_{\mathrm{EX}} \cdot N}$$

where RLI_t is the RLI value at time t; $c(t,s)$ is the IUCN Red List category of species s at time t;, W_c is the weight for category c; W_{EX} is the weight assigned to extinct species (this equals 5 using the recommended 'equal steps' weights, with Critically Endangered = 4, Endangered = 3, Vulnerable = 2, Near Threatened = 1, Least Concern = 0; see Butchart *et al.* 2004 for further discussion); and N is the total number of assessed species, excluding those considered Data Deficient and those assessed as Extinct in the year the set of species was first assessed.

Following the approach outlined by Butchart *et al.* (2007), four data points were calculated (1988, 1994, 2000, 2004) corresponding to the comprehensive assessments of all bird species for the IUCN Red List carried out by BirdLife International. The 2004 RLI data point was calculated using the 2004 totals updated by subsequent revisions published in partial updates (up to 2007), thereby reflecting the most up-to-date information available. Red List categories for each species in earlier assessments (1988, 1994 and 2000) were assumed not to be different to the 2007 category, unless there was adequate evidence for a genuine improvement or deterioration in status since 1988 that was sufficient for the species to have crossed the thresholds for a higher or lower Red List category.

For each genuine category change, the primary driver of the change in status was identified in order to calculate RLIs showing the impacts of utilisation and invasive species on the status of the world's birds. More specifically, information was extracted from BirdLife's extensive datasets on population size and trend, range size and trend, ecology, life history, threats (including threat magnitude, timing, scope, severity and stresses; see: http://www.birdlife.org/datazone/species/terms/threats.html), and conservation actions implemented and underway (all of which is synthesised in the World Bird Database, and summarised in the published species factsheets at http://www.birdlife.org/datazone/species/index.html), including the data sources, unpublished literature and correspondence underpinning the published Red List assessments. Both current information and earlier assessments were examined. For each genuine status change, the parameter that increased or decreased sufficiently to cross a Red List category threshold was identified (e.g. the population size fell below 250 mature individuals, the number of locations increased to six owing to successful establishment of a translocated population etc). Then, for the specific parameter for each species, the *primary* driver of change was categorised as: (a) invasive species (negative impacts, or successful control or eradication); (b) exploitation (unsustainable use for food, pets, etc., or reduction in use through successful management or control); or (c) other issues (most commonly, habitat degradation or destruction). It was generally straightforward to determine which of these three categories applied. Where one of these factors was a contributory, rather than the primary, driver, this was also recorded. As a conservative approach was taken in identifying genuine status changes (i.e. adequate documentation must be available to be confident that a genuine status change has taken place), there was always sufficient contextual information on threats and drivers to assign the driver confidently as described above. For those status changes driven by exploitation, the primary purpose and scale of use were also determined.

In order to compare the importance of different factors driving trends, it is simpler to interpret RLIs with a common starting point rather than a common end point (i.e. to ask the question 'what would be the status of all species now if only factor X or Y had been operating over recent years?', rather than 'what would have been the status of all species in year A if only factor X or Y had driven them to today's status?'). To achieve this, the initial RLI data point (for 1988) for each factor was set to the value calculated for the set of species considering status changes driven by all factors. Hence, these RLIs show, for the set of species concerned, the net effect of status changes driven only by the particular factor concerned. This permits a more logical comparison than starting from the present RLI value and asking what trajectory the RLI would have taken to reach that value if it had been driven by different factors.

The relative importance of factors driving trends in the RLI was tested using binomial tests on the number of genuine status changes driven by one factor versus others. RLIs for different sets of species cannot easily be compared statistically to see if their slopes differ significantly. Methods are still being developed to assess the impacts of uncertainty in Red List categorisations on RLI values and trends, and hence to permit statistical comparisons of slopes.

Interpreting the RLI

RLI values relate to the proportion of species expected to remain extant in the near future without additional conservation action. An RLI value of 1.0 equates to all species being

categorised as Least Concern, and hence that none is expected to go extinct in the near future. An RLI value of zero indicates that all species have gone Extinct. A downwards trend in the graph line (i.e. decreasing RLI values) means that the expected rate of species extinctions is increasing, i.e. that the rate of biodiversity loss is increasing. A horizontal graph line (i.e. unchanging RLI values) means that the expected rate of species extinctions is unchanged. An upward trend in the graph line (i.e. increasing RLI values) means that there is a decrease in expected future rate of species extinctions (i.e. a reduction in the rate of biodiversity loss).

Data on the use of bird species

The utilisation of birds by humans was categorised for all bird species for the first time using the IUCN Utilisation Classification Scheme (http://intranet.iucn.org/webfiles/doc/SSC/RedList/AuthorityF/utilization.rtf). This records the purpose of use (with the main uses relevant to birds being: food, pets, medicine, sport hunting and wearing apparel/ornamentation), along with the source (wild, captive breeding or ranching), primary form taken (whole individual or non-lethal removal of parts), life stage (adult, chicks, eggs), and scale (international/regional, national/subnational or local/subsistence) for each record of use for each species. Data to populate the classification scheme were taken from over 100 sources and datasets, mainly relating to species recorded in trade, at wildlife markets, seized at international borders or hunted. In total, 17,254 records of use were extracted from these sources. Records of use were excluded from the subsequent analyses if they clearly referred to historical utilisation (pre-1980s for the purposes of these analyses), or if they were considered likely to involve trivial numbers of individuals. All these data will be available from autumn 2008 at http://www.birdlife.org/datazone/species/index.html and at www.iucnredlist.org.

Data on invasive species threatening birds

The threats to all Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable and Near Threatened bird species were identified and categorised using the (newly revised) IUCN Threats Classification Scheme (http://conservationmeasures.org/CMP/Site_Docs/IUCN-CMP_Unified_Direct_Threats_Classification_2006_06_01.pdf). Threats from invasive species were for the first time identified to individual invasive species. These data are available for all bird species at http://www.birdlife.org/datazone/species/index.html and will be from autumn 2008 at www.iucnredlist.org.

How sustainable is the use of the world's birds?

Results

Evidence of utilisation by humans was found for a total of 4,561 bird species, representing 45.7% of the world's 9,990 extant and extinct bird species. Excluding historical uses and those species for which trivial numbers of individuals are involved gives a total of 4,173 species (42.3% of 9,856 extant species). Among these, two purposes of use dominate: 3,649 species (37.0% of extant species, 87.4% of utilised species) were recorded as being used as pets, and 1,398 species (14.2% of extant species; 33.5% of utilised species) were recorded as being hunted for food (Fig. 1). Less significant uses include sport hunting, wearing apparel or ornamentation and medicine (usually traditional), with trivial numbers of species being recorded as used for handicrafts, fuel (from oil or fat, principally from seabirds) and household goods (e.g. down for mattresses), etc. Many species are used in more than one way; for example, 68.9% of species that are hunted for food are also kept as pets.

Excluding historical and trivial uses, a total of 3,337 species (33.9% of extant species) were recorded as being traded internationally, all for the pet trade, although some are internationally

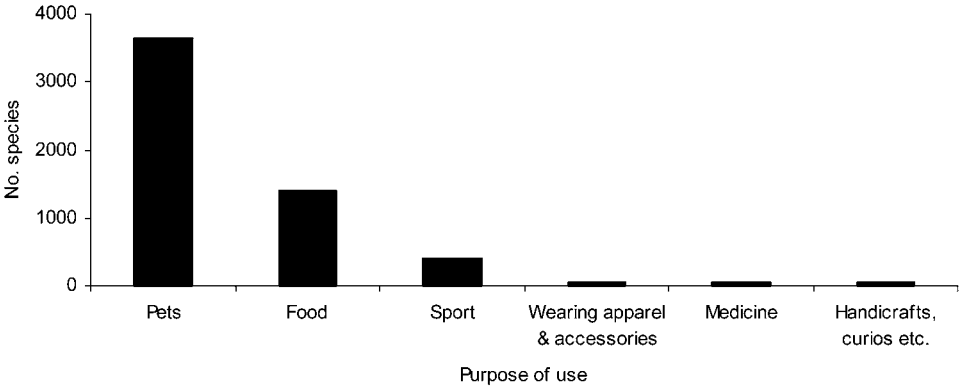

Figure 1. Number of bird species recorded for different purposes of use (n = 17,254 records of use for 4,561 out of 9,856 extant species).

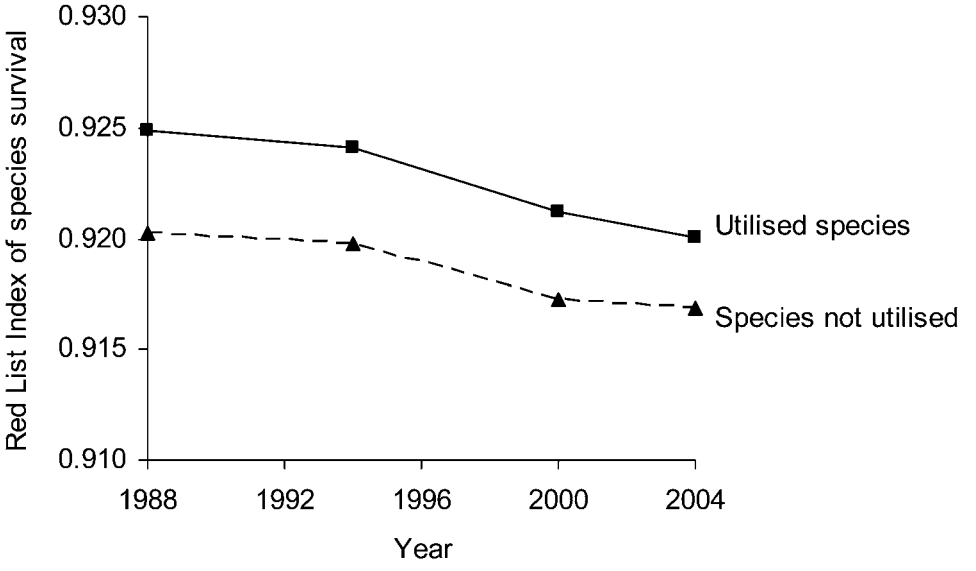

Figure 2. Red List Index (RLI) for utilised species (n = 4,481 non-Data Deficient species) and species not utilised (5,402 species), in each case showing the proportion of species expected to remain extant in the near future without additional conservation action.

traded for additional purposes. At least 46.5% of internationally traded species (1,552 species) were also recorded in national/local trade, but the exceptions probably reflect lack of data rather than being species that are genuinely targeted only for international trade rather than local use.

These data can be used to develop RLIs showing trends in the extinction risk of the world's birds related to use. Utilised species are overall less threatened with extinction than non-utilised species (in Fig. 2 the RLI for utilised species has higher values than that for non-utilised species: an RLI value of 1.0 equates to all species being Least Concern and therefore having low risk of extinction, while an RLI value of zero indicates all species have gone extinct). The RLI for utilised species shows an overall decline during 1988–2004 (Fig. 2). Although some species have been downlisted to lower categories of threat owing to successful reduction in over-exploitation

and other types of conservation action, many more have been uplisted to higher categories of threat owing to increasing threats, including over-exploitation, driving faster population declines and leading to smaller population and range sizes. The RLI shows that the net effect of these up- and down-listings has been an overall reduction in the proportion of species expected to remain extant in the absence of additional conservation action, i.e. that this set of species is slipping further towards extinction.

Over the period 1988–2004, utilised species and non-utilised species have undergone similar rates of decline: the RLIs are more or less parallel (Fig. 2). However, issues related to use (over-exploitation or successful management/control of exploitation) are not the only factors impacting utilised species. By scoring the primary cause of Red List category changes driving trends in the RLI, it is possible to tease out trends driven by different factors. Trends driven by issues related to use drove a deterioration in the status of the world's birds, but this was significantly outweighed by trends driven by other factors combined, such as habitat loss, invasive species impacts, etc. (use factors drove 17.9% of 234 genuine status changes; binomial test, $z = 271.1$, $P < 0.0001$; Fig. 3). The rate of deterioration was greater when the RLI was calculated including species changing status where issues related to use were a contributory, rather than the primary, driver, but this was still significantly outweighed by trends driven by other factors (use issues drove or influenced status changes for 26.9% of species, $z = 88.48$, $P < 0.0001$).

Even among utilised species, trends driven by use were outweighed by non-use factors combined (use factors drove 30.7% of 137 genuine status changes in utilised species; binomial test, $z = 133.9$, $P < 0.0001$). The pet trade and hunting for food drove similar rates of decline, but were outweighed by trends driven by other factors combined even when incorporating trends for which the use was a contributory factor as opposed to a primary driver (Fig. 4).

Internationally traded species are less threatened overall than other species (as with all utilised species), but species that are apparently used only at a national scale appear substantially more threatened (their RLI has lower values in Fig. 5). Among internationally traded species, factors related to international trade (unsustainable levels or successful control or management of such trade) have overall caused a deterioration in the extinction risk of these species (Fig. 6). Although some species have improved in status through successful control of unsustainable trapping and

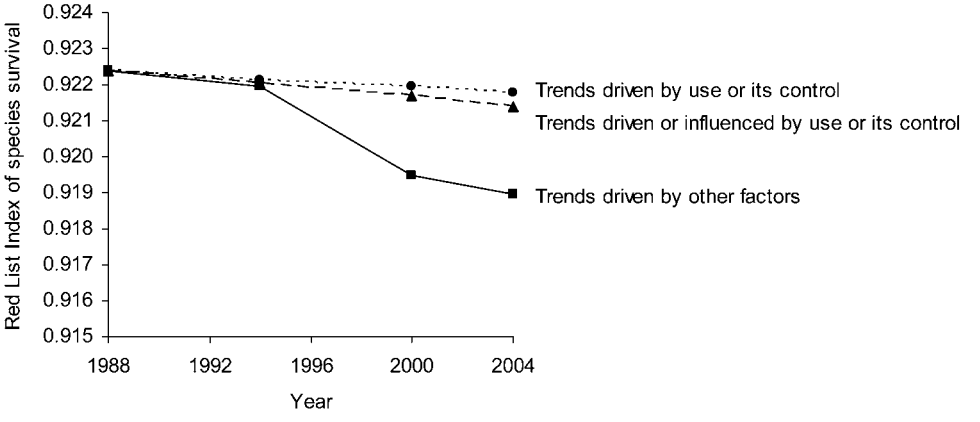

Figure 3. Red List Index (RLI) for all species, showing trends driven by use (or its control and management) (dotted line) compared to trends driven by other factors combined (e.g. habitat loss) (solid line), for the proportion of species expected to remain extant in the near future without additional conservation action. Dashed line also includes cases where use contributed to trends but was not the primary driver of the change in status; $n = 9{,}883$ non-Data Deficient species.

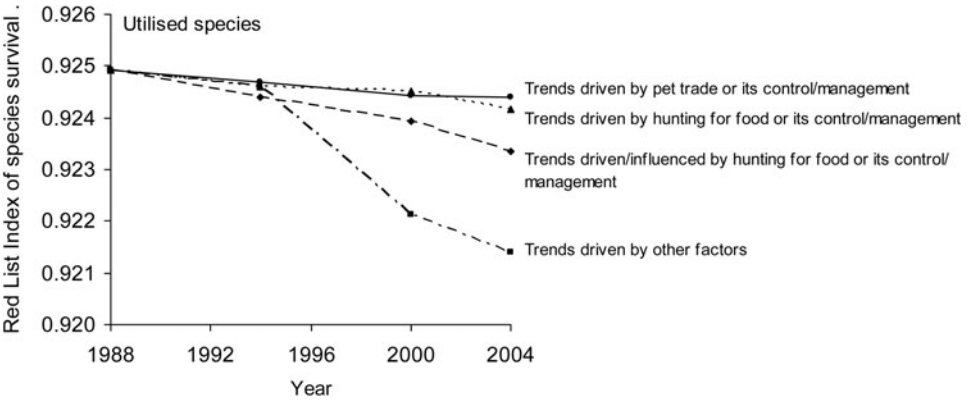

Figure 4. Red List Index (RLI) for utilised species, showing trends driven by use (or its control and management) compared to trends driven by other factors combined (e.g. habitat loss), for the proportion of species expected to remain extant in the near future without additional conservation action; n = 4,481 non-Data Deficient species. Dashed line also includes cases where hunting for food contributed to trends but was not the primary driver of the change in status.

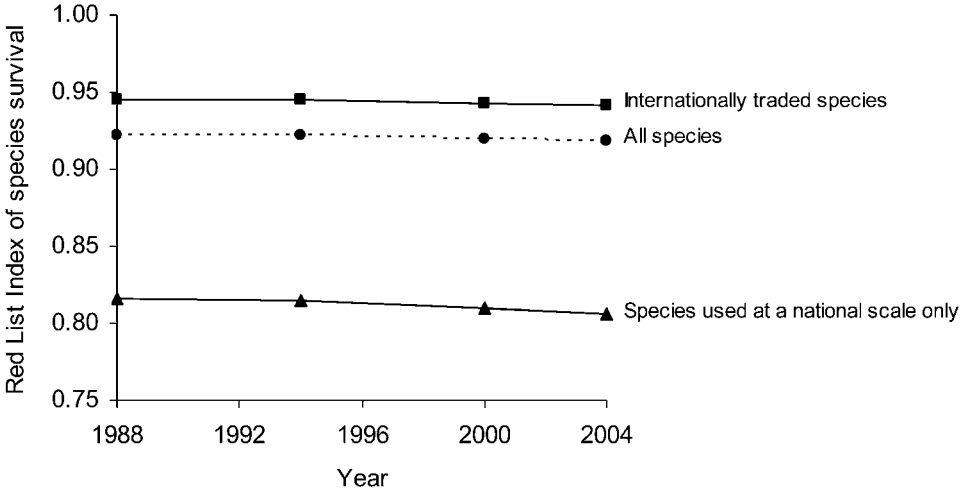

Figure 5. Red List Index (RLI) for internationally traded species (n = 3,736 non-Data Deficient species), species utilised at a national scale only (745 species), and all species (9,883 species), in each case showing the proportion of species expected to remain extant in the near future without additional conservation action.

trade and/or improved harvest and trade management (e.g. Lear's Macaw *Anodorhynchus leari*, Imperial Amazon *Amazona imperialis*), these improvements have been outweighed by the number of species that have deteriorated in status owing to inadequate trade management or implementation of trade controls (e.g. Saker Falcon *Falco cherrug*, Yellow-crested Cockatoo *Cacatua sulphurea*). Hence the RLI showing trends driven by international trade or its management and control also shows a negative slope (Fig. 6). However, this is again outweighed by trends driven by factors other than international trade (Fig. 6; international trade issues drove 16.1% of 93 genuine status changes among internationally traded species; binomial test, z =

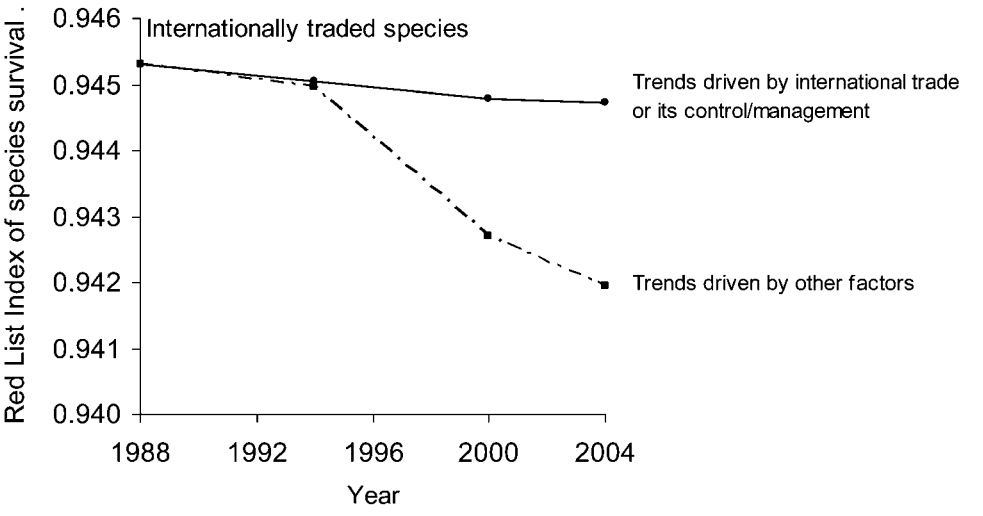

Figure 6. Red List Index (RLI) for internationally traded species, showing trends driven by international trade (or its control and management) compared to trends driven by other factors combined (e.g. habitat loss), for the proportion of species expected to remain extant in the near future without additional conservation action; $n = 3{,}736$ non-Data Deficient species.

20.56, $P < 0.0001$), even when including cases where use issues were a contributory, rather than the primary, driver ($z = 21.98$, $P < 0.0001$).

Discussion

Although over-exploitation is one of the most important threats to biodiversity, utilisation of biodiversity is enshrined in the principles of sustainable development (IUCN, UNEP and WWF 1980, United Nations 1987), and has been advocated as a powerful tool in conservation (e.g. MacKinnon 1998). Progress has been made in defining sustainable use and in guiding how sustainability may be achieved (e.g. the Addis Ababa Principles: Secretariat of the Convention on Biological Diversity 2004), but ensuring sustainability and measuring progress towards this remain serious challenges. Currently proposed indicators of sustainable use do not address the issue of tracking trends in the impacts of use on biodiversity, i.e. the degree to which use is sustainable, in the broadest sense.

This study represents the first comprehensive assessment of the extent and sustainability of use by humans for a complete class of organisms: birds. I found that almost half of bird species are exploited by people for one or more forms of consumptive use. This substantial proportion highlights how intimately connected people are to birds. The vast majority of these species are used as cage-birds, with hunting for food and sport also being major forms of use. Less common usages include, for example, harvesting feathers for bedding (e.g. Common Eider *Somateria mollissima*: Kear 2005) and ornaments (e.g. bird of paradise plumes used in tribal head-dresses: Frith and Beehler 1998), oil for fuel (e.g. Oilbird *Steatornis caripensis*: del Hoyo *et al.* 1999), skin for leather (e.g. Greater Rhea *Rhea americana*: del Hoyo *et al.* 1992), traditional medicine (e.g. Hispaniolan Lizard-cuckoo *Coccyzus longirostris* as a 'cure' for indigestion: del Hoyo *et al.* 1997) and ornamentation (e.g. skulls of Papuan Hornbill *Aceros plicatus* worn for decoration: Kemp 1995).

It is perhaps surprising that the pet trade seems substantially more significant (in terms of numbers of species) than hunting for food, but this may reflect the fact that hunters tend to take the commonest species (whereas rarity may make a species attractive as a cage-bird). It may also

represent a bias in the data, as the hunting of less common species for food (usually for local consumption) is more difficult to gather data on than the trade of cage-birds (which is amenable to data-collection at pet markets or international borders).

It is currently difficult to estimate the volume of use (numbers of individuals) for different types of use, but the totals are likely to be substantial. The number of individual birds sold each year in international trade at the start of the 1990s was estimated to be c.2–5 million, and the number of individual birds *taken* each year for international trade at that time may have been up to 10 million—since as many as half the birds could have died before they reached a dealer (Mulliken *et al*. 1992). The estimated numbers taken and sold in domestic trade is not known, but may well be on a similar scale (Mulliken *et al*. 1992). In terms of hunting for sport and food, Hirschfeld and Heyd (2005) estimated that at least 102 million individuals of the 82 bird species listed on Annex II of the EU Birds directive were killed in the EU during 2001–2003, while Magnin (1991) estimated that 0.5–1 billion songbirds are killed each year in Europe, with 100–150 million a year killed in Italy alone.

The estimated proportion of all bird species that are involved in the international bird trade can now be increased from a quarter (UNEP 2007) to over a third (34%). The impact of this trade on the status of species is generally rather poorly understood. A total of 345 threatened bird species (i.e. those listed as Vulnerable, Endangered, Critically Endangered or Extinct in the Wild) are threatened by over-exploitation (representing nearly 30% of extant threatened bird species). This includes 117 (10%) that are threatened by trapping for the cage-bird trade (BirdLife International 2004). Unsustainable exploitation is particularly prevalent in Asia, with Indonesia and China holding the largest numbers of species that are threatened by exploitation (BirdLife International 2004). A more recent analysis (BirdLife International unpublished data 2005) showed that the international cage-bird trade in particular is a contributory factor to the threat status of 88 (*ca*. 5%) of threatened and Near Threatened bird species, and a *significant* threat to 55 threatened and Near Threatened species.

Red List Indices using these data can help indicate the sustainability of use of the world's birds, and how this changes over time. They show that utilised species are overall less threatened with extinction than non-utilised species. This is perhaps not surprising: people tend to use those species that are easiest to exploit, which are often the commonest (and hence less threatened), notwithstanding the value attached to rarity for at least some types of use. However, utilised species have deteriorated in status at a similar rate to non-utilised species during 1988–2004. Fig. 3, which can be used as an RLI showing the overall sustainability of use, shows that the status of the world's birds is deteriorating overall as a consequence of unsustainable levels of use. However, it also demonstrates that other factors combined were more important in driving trends than issues related to utilisation (including over-exploitation and its successful management/control), underlining the fact that habitat loss and degradation (principally deriving from the impacts of agriculture, logging, residential/commercial development, etc.) is the primary threat to the world's birds (BirdLife International 2004). Within utilised species, a finer-scale analysis (Fig. 4) shows that the pet trade and hunting for food drove similar rates of decline, but were outweighed by trends driven by other factors.

International trade is recognised as being of particular concern for biodiversity, such that it has its own international political agreement: the Convention on International Trade in Endangered Species (CITES, www.cites.org). Internationally traded species are less threatened overall than other species, presumably for the same reasons as given above for utilised species. The finding that species used only at a national scale appear substantially more threatened may well be an artefact of the dataset. It is more difficult to find data on local- or national-scale use of species than international ones, so the number of species that are locally hunted and consumed (and never or rarely traded internationally) is likely to be underestimated in our dataset, with a bias towards the better-documented threatened species.

While international trade may be an important factor contributing to the threatened status of a substantial number of species, relatively few (14) have deteriorated sufficiently in status since

1988 as a consequence of unsustainable international trade to be uplisted to higher categories of threat, and only two species have improved in status sufficiently as a result of action tackling international trade to be downlisted to lower categories of threat. The balance of these two effects determines the net slope of the RLI for trends driven by international trade (upper line in Fig. 6), and as such could be one useful measure of the efficacy of CITES, albeit at a coarse scale. For CITES to be helping to reduce the rate of loss of biodiversity as shown by the RLI, this line needs to show a positive slope, as this will indicate that there is an increase in the proportion of species expected to remain extant in the near future as a result of effective trade controls, i.e. a decrease in the expected future rate of species extinctions and hence a reduction in the rate of biodiversity loss. The ultimate goal should, of course, be that no species is threatened by international trade. The current downwards trajectory of this RLI shows that considerable challenges remain.

This RLI is an indicator of the ultimate impact of CITES-related measures to manage and control trade. In the majority of cases where a species is uplisted to a higher category of threat owing to increasing levels of exploitation for international trade, it is currently not possible (using the data available) to determine the relative importance of subnational versus international trade, and legal versus illegal trade, in driving declines in that species's population. Similarly, when a species is downlisted to a lower category of threat owing to the successful control or management of trapping and trade, the relative roles of improved nest protection, implementation of national legislation, more sustainable harvest levels and implementation of international controls (through CITES) cannot always be distinguished. This means that the indicator may reflect a combination of factors related to trade, some of which are outside the jurisdiction of CITES.

It is important to emphasise that the RLI provides a fairly coarse measure of changes in the status of biodiversity (i.e. it has relatively coarse temporal resolution). This is because of the broad nature of the Red List categories: a species may have to undergo quite substantial changes in population size, rate of decline or range size in order to cross the thresholds for a higher or lower Red List category, and hence to contribute to the RLI trend. In practice this means that many species may be undergoing declines as a consequence of unsustainable exploitation, but to an extent that has yet to result in their uplisting on the IUCN Red List. This biodiversity loss is less easy to measure and track over time, but should not be overlooked. Gathering data on which Least Concern species may be being currently harvested unsustainably (and hence which may become candidates for Near Threatened or threatened status in due course) would be desirable.

Further refinement of these RLIs could involve attempting to quantify levels of international trade in order to distinguish those species traded in numbers above a certain (arbitrary) threshold. This would allow one to examine trends in those species that are commonly traded, and exclude species that are rarely found in international trade. However, adequate data are probably unavailable to permit this at present.

Data on the use of species are now being collected for other taxa on the IUCN Red List, and complete assessments of all species will soon be available for amphibians for 2004–2010, mammals for 1996–2008 and cycads for 2000–2008. RLIs as indicators of sustainable use will be developed for these groups also in due course. In addition, a randomly selected sample of reptiles, fish, plants and invertebrates is currently being assessed, and these assessments will allow the development of RLIs more broadly representative of all biodiversity.

What is the overall impact of invasive species on the world's birds?

Results

One third of the world's threatened bird species (398 species, 32.6%), and over one quarter of threatened, Near Threatened and Extinct bird species (597, 27.2%) are or were impacted by invasive species. Of these 597 species, the majority are impacted by alien invasive mammals (484

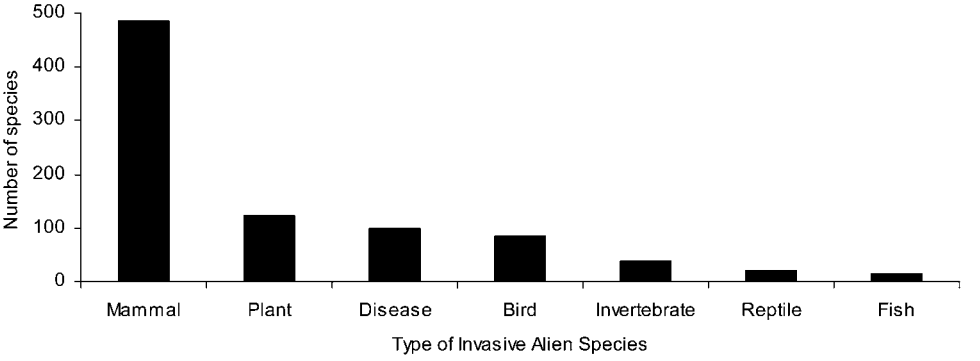

Figure 7. Number of bird species impacted by different types of Invasive Alien Species ($n = 597$ threatened, Near Threatened and Extinct species).

species, 81.1%), with plants impacting 20.6% (123 species) and disease/micro-organisms and birds impacting 16% and 14% of species respectively (Fig. 7). Among mammals, carnivores impact 52.3% of bird species affected by invasive species (312 species, with domestic cat *Felis catus* being the most important, affecting 254 species), rodents impact 52.6% (314 species, with Black Rat *Rattus rattus* affecting at least 94 species), and ungulates impact 27.0% (161 species, with domestic pig *Sus domesticus* affecting 82 species). Among other classes, Common Myna *Acridotheres tristis* is the most important invasive bird species, impacting 21 species, Brown Tree Snake *Boiga irregularis* the most important reptile (20 species) and avian malaria *Plasmodium relictum* (17 species) and avian pox *Poxvirus avium* (12 species) the most significant diseases.

Invasive species impact threatened species in different ways, with 63.8% (381) of species threatened by invasive species suffering direct mortality by predators, 63.0% (376 species) suffering reduced reproductive stress (usually through predation of eggs or chicks), 38.4% (229 species) affected by degradation of their habitats (by herbivores and/or invasive plants) and 12.4% (74 species) impacted by competition for food, nesting sites, etc. Smaller proportions of species ($< 3\%$ each) are impacted by indirect ecosystem effects, disturbance, habitat conversion, hybridisation and skewed sex ratios (Fig. 8).

During 1988–2004, 41 bird species underwent genuine changes in status (as measured by movement through categories of the IUCN Red List) owing largely to issues related to IAS. This included 31 species that were uplisted to higher categories of threat because of population

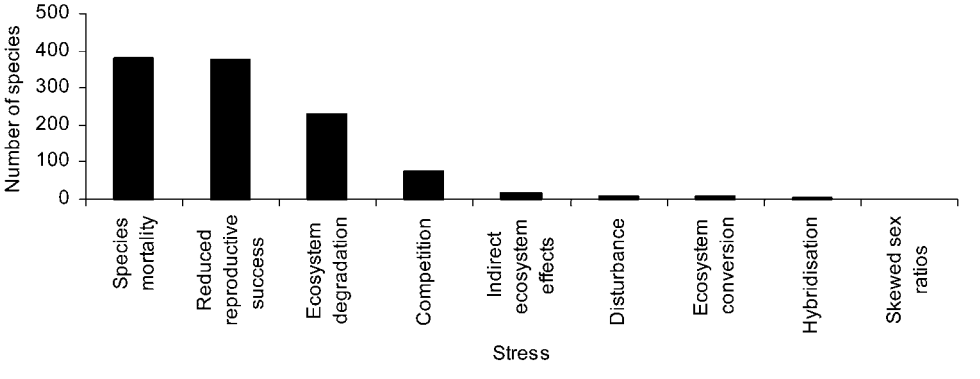

Figure 8. Number of bird species impacted in different ways by Invasive Alien Species ($n = 597$ threatened, Near Threatened and Extinct species).

declines driven by the impacts of invasive species, and ten species that were downlisted to lower categories of threat as a consequence of successful control or eradication of invasive species. For example, Yellowhead *Mohoua ochrocephala* was very seriously affected by rat irruptions in New Zealand in 1999–2000, with two populations going extinct, and three more having significant population crashes. By 2000, the rate of decline is suspected to have exceeded 50% over ten years, which would have qualified the species for uplisting from Vulnerable to Endangered (BirdLife International 2007a). In contrast, the population of Black-vented Shearwater *Puffinus opisthomelas* declined through the 1990s as a result of cat predation and the impacts of other invasive species on islets off the Pacific coast of Mexico, but successful eradication of goats and sheep in 1997–1998 and cats in 1999 from Natividad (which holds the vast majority of the world population) reduced mortality dramatically in the 2000s, qualifying the species for downlisting from Vulnerable to Near Threatened by 2004 (BirdLife International 2007b).

These data on species undergoing genuine status changes can be represented graphically as the cumulative percentage of species over time undergoing such up- or down-listings (Fig. 9). The RLI combines both the species that have deteriorated in status owing to negative impacts of invasive species, and the species that have improved in status owing to successful eradication or control programmes, and it integrates the numbers and size of status changes for both sets of species into a single graph showing the overall impact of invasive species on the world's birds.

This shows that, overall, the world's birds deteriorated in status during 1988–2004 owing to invasive species issues (Fig. 10). This decline would have been substantially steeper had conservation action tackling invasive species not resulted in the downlistings of a suite of species. Hence, while invasive species were a significant driver of trends, their overall effect was outweighed by trends driven by other factors combined (invasive species drove 17.5% of 234 genuine status changes; binomial test, $z = 57.34$, $P < 0.0001$), even when including trends for which invasive species issues were a contributory, rather than the primary, driver ($z = 75.74$, $P < 0.0001$; Fig. 10). Among species downlisted to lower categories of threat, control or eradication of invasive species was a significant driver for 31.3% ($z = 20.67$, $P = 0.015$), and a significant or contributory factor for 50% ($z = 22.09$, $P = 0.14$).

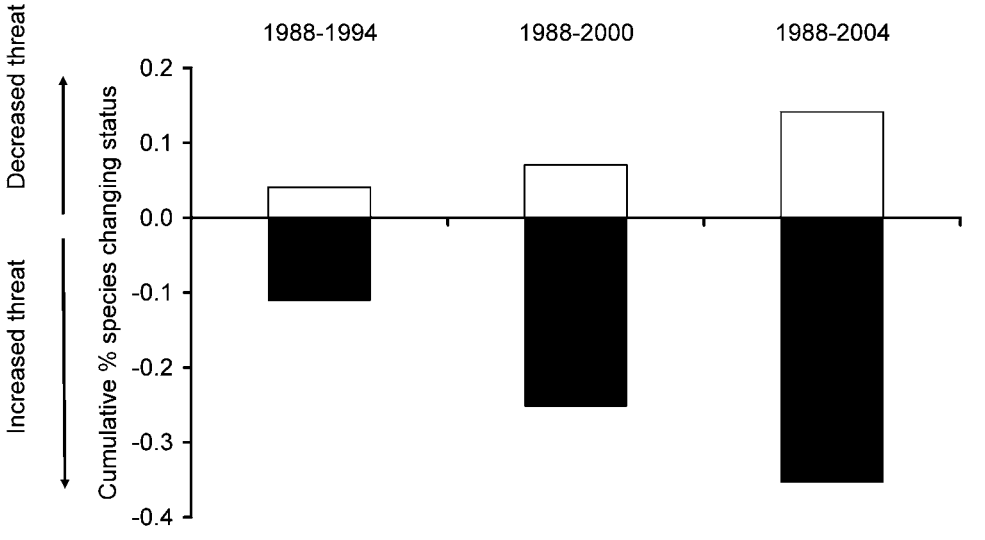

Figure 9. Number of species (expressed as a cumulative percentage of all species) undergoing genuine status changes driven by the impacts of Invasive Alien Species, including impacts leading to deterioration in status (solid bars) and eradication/control measures leading to improvements in status (open bars), for three time-periods between 1988 and 2004; $n = 3{,}014$ non-Data Deficient species.

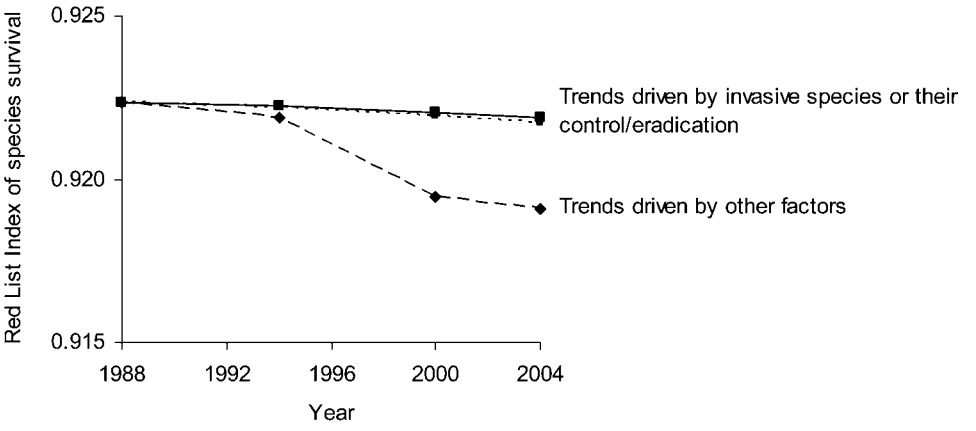

Figure 10. Red List Index (RLI) showing trends driven by the impacts of Invasive Alien Species compared to trends driven by other factors combined (e.g. habitat loss), for the proportion of species expected to remain extant in the near future without additional conservation action; n = 9,883 non-Data Deficient species. Dotted line also includes cases where invasive species contributed to trends but were not the primary driver of the change in status.

Discussion

Invasive species are one of the key threats to biodiversity (Mooney and Hobbs 2000, Mooney *et al.* 2005). They are one of the top three threats to threatened birds, impacting almost 30% of threatened species (BirdLife International 2004), and have been a major driver of avian extinctions, being a contributory or primary factor behind 51% of extinctions since 1500 (and second in importance only to habitat loss and degradation: Blackburn *et al.* 2004, Butchart *et al.* 2006b). The results presented here augment these previous studies to give a finer-scale picture. Among invasive species, it is mammalian predators, particularly carnivores and rodents, that pose the greatest threat, largely through directly predating birds (including adults, chicks and eggs). In addition, ungulates and invasive plants pose a significant threat to birds through the degrading effects they have on habitat quality.

Many bird species are impacted by multiple invasive species, and their negative impacts may be synergistic. For example, on the Hawaiian island of Maui, the Critically Endangered Akohekohe *Palmeria dolei* is threatened by both avian malaria and avian pox, transmitted by invasive mosquitoes, whose spread is facilitated by the effect of introduced pigs on native vegetation (Pratt 1994, Loope and Medeiros 1995, Rosa *et al.* 1998, BirdLife International 2007c).

While some progress has been made in designing potential indicators to track trends in the numbers and spread of invasive species, and in the management actions to reduce these (McGeoch *et al.* 2006), no indicator has previously been proposed to measure global trends in the impacts of invasive species on biodiversity. The RLI for impacts of invasives on birds (Fig. 10) fills this gap. It shows that, despite a substantial number of successful recoveries following conservation measures tackling invasives, overall the status of the world's birds has continued to deteriorate as a consequence of negative impacts of invasive species.

These data counter the claim made by Gurevitch and Padilla (2004) that invasive species are not a major threat to threatened species (which was based on inadequate analysis of outdated and incomplete data) and supports the counter-argument by Clavero and García-Berthou (2005) that invasive species are indeed a significant threat to the world's birds and other biodiversity, and a

major driver of recent extinctions. Nevertheless, other factors combined, including habitat loss in particular, have been more important drivers of recent genuine Red List category changes.

As with the RLI as an indicator of sustainable use, further refinements are needed for this indicator. For many species it was not possible with the information available to assign the invasive species specifically, e.g. for 201 bird species threatened by rats, it was not possible to determine the actual species: further research of the literature and expert input is required. Further linkages with the Global Invasive Species Database (www.issg.org/database) will also help to further improve the dataset. Finally, the calculation of RLIs for other taxa, starting with mammals and amphibians, will broaden the representativeness of the aggregated RLI.

Conclusions

The data and RLIs presented here highlight the importance of unsustainable use and invasive species as threats to the world's birds, and as drivers of the deteriorating trends in their status. Similar patterns are known or expected for other classes of organisms (Baillie *et al*. 2004). Substantially increased efforts are needed to (a) control or manage hunting and national and international trade (both legal and illegal) where this is shown or suspected to be unsustainable; (b) limit potential introduction and range expansion pathways of invasive species; and (c) manage, control or eradicate those populations of invasive species that have already become established. Such measures are essential if progress in slowing the rate of biodiversity loss is to be achieved. RLIs for the impacts of use and of invasive species will be important indicators to help track progress towards this aim.

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